RADIO LINE AND CONTINUUM OBSERVATIONS OF QUASAR-GALAXY PAIRS AND THE ORIGIN OF LOW REDSHIFT QUASAR ABSORPTION LINE SYSTEMS

C.L. Carilli (CfA), J.H. van Gorkom, E.M. Hauxthausen (Columbia Univ. and NRAO), J.T. Stocke (Univ. of Colorado), and J. Salzer (Univ. of Michigan)

Abstract

There are a number of known quasars for which our line of sight to the high redshift quasar passes within a few Holmberg radii of a low redshift galaxy. In a few of these cases, spectra of the quasar reveal absorption by gas associated with the low redshift galaxy. A number of these pairs imply absorption by gas which lies well outside the optical disk of the associated galaxy, leading to models of galaxies with 'halos' or 'disks' of gas extending to large radii. We present observations of 4 such pairs. In three of the four cases, we find that the associated galaxy is highly disturbed, typically due to a gravitational interaction with a companion galaxy, while in the fourth case the absorption can be explained by clouds in the optical disk of the associated galaxy. We are led to an alternative hypothesis concerning the origin of the low redshift absorption line systems: *the absorption is by gas clouds which have been gravitationally stripped from the associated galaxy.* These galaxies are rapidly evolving, and should not be used as examples of absorption by clouds in halos of field spirals. We conclude by considering the role extended gas in interacting systems plays in the origin of higher redshift quasar absorption line systems.

A. 1327-206

This systems is one in which a radio loud quasar, PKS 1327-206 ($z_Q = 1.17$), sits 37" from the galaxy ESO 1327-2041 ($v_G = 5370$ km s^{-1})[1]. Deep optical plates show that ESO 1327-2041 is a polar ring galaxy[2]. The quasar projects behind the outer part of the ring to the east. High resolution spectra show narrow NaI absorption at velocities of 5246 and 5484. Lower resolution spectra show broad CaII absorption at a velocity of 5346 km s^{-1}.

In figure 1 we present our new radio observations of this galaxy. We find that the quasar continuum is extended, and that the galaxy ESO 1327-2041 is also radio loud, with an integrated flux of 12 mJy. We detect HI in absorption against the quasar core coincident in velocity with the low velocity optical absorption system ($v_{abs} = 5257$ km s^{-1}, FWHM $\leq$ 11 km s^{-1}). The column density in HI is $3.1 \times 10^{17} \times T_s$ cm^{-2}. We detect no absorption associated with the high velocity optical system to a 3σ column density of $1.7 \times 10^{17} \times T_s$ cm^{-2}.

The HI emission from ESO 1327-2041 confirms the idea that this is a polar ring galaxy. We find that the HI in ESO 1327-2041 rotates about an axis which is parallel to the minor axis *of the ring, and hence perpendicular to the minor axis of the dominant optical galaxy. The* total HI mass observed by the VLA is 7×10^9 $M_\odot$. A Nancay spectrum of this galaxy found a factor of three times more HI, which suggests an extended component in HI[6]. The optical and HI morphology suggest that ESO 1327-2041 is a system far from dynamical equilibrium,

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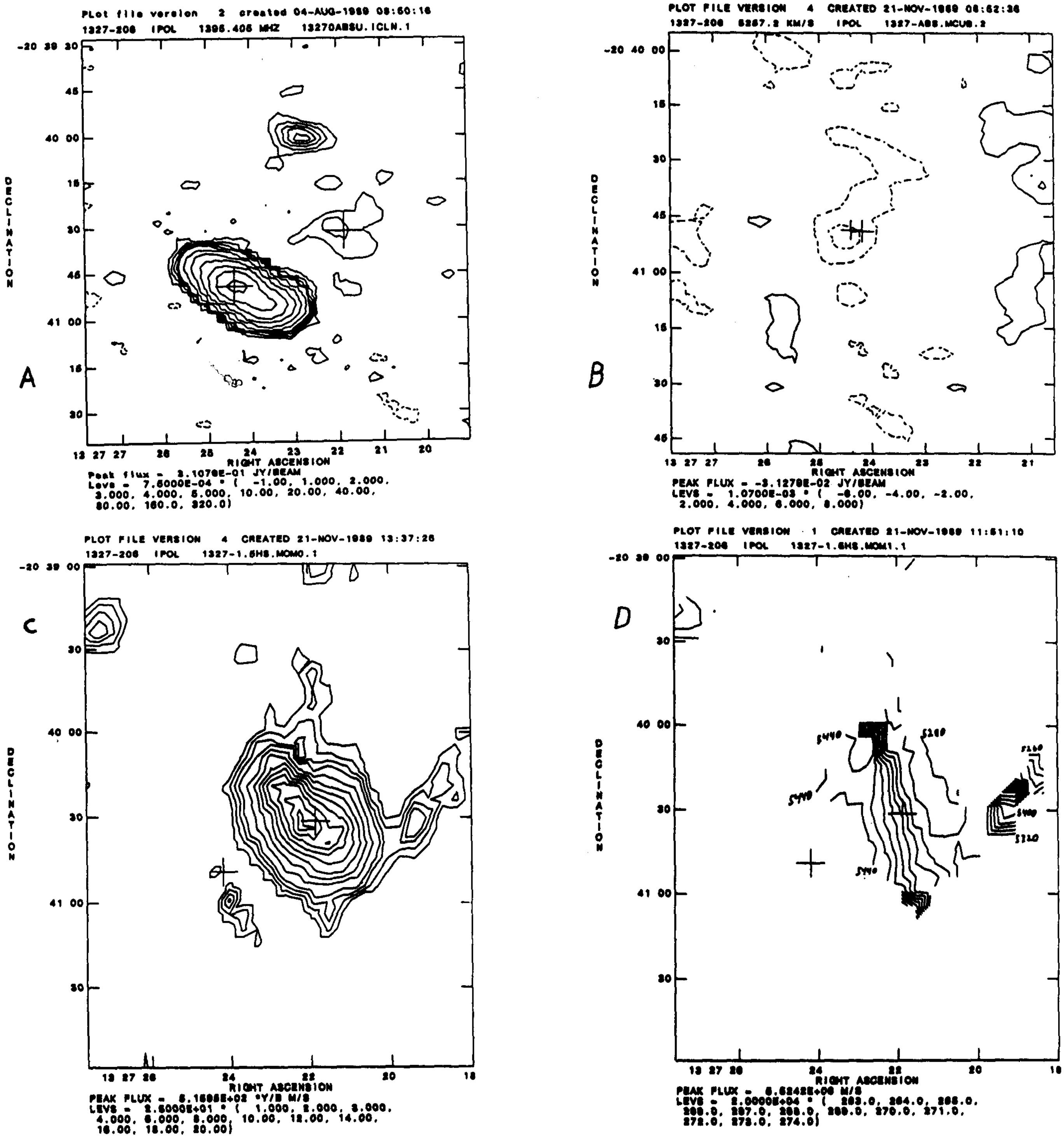

Fig. 1: Images of pair 1327-206. Crosses mark the position of the optical galaxy and the radio continuum peak of the quasar. Spatial resolution is 17". A. Continuum emission at 1396 MHz. B. Absorption channel (5257 km s^{-1}) at 10.5 km s^{-1} resolution. The smaller cross indicates the position of the optical quasar. C. HI column density. Units are 10^{20} cm^{-2}. D. Velocity field of HI.

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which is evolving on dynamical timescales ($\leq 10^9$ years), much like the ring galaxy M -5-7-1 studied by van Gorkom *et al.* (1987).

The high velocity optical absorption line system fits in well with the observed rotation curve in HI, and implies flat rotation out to at least 20 kpc. The dynamical mass within this radius is 1.2x10^{11} $M_{\odot}$(using $i = 45^o$). Of course, if the system is far from dynamical equilibrium then the rotational velocity may not be a good indicator of total dynamical mass. The low velocity absorption system has an anomolous velocity of 200 km $s^{-1}$with respect to the rotating HI. The most likely origin for this anomalous system is a cloud which has been accelerated during the merger, and has not had time to reach dynamical equilibrium.

B. 3C 232

The quasar 3C 232 ($z_Q = 0.513$) sits 2' north of the galaxy NGC 3067 ($v_G = 1456$ km s^{-1}). NGC 3067 displays a highly disturbed optical morphology, with prominent dust lanes and bright knots of Hα emission distributed throughout the disk[7]. The galaxy also has a large IRAS flux and radio continuum flux[8], which put it in the class of starburst galaxies such as M82. A starburst could be triggered by a recent merger. Note that this galaxy is an isolated spiral.

Optical spectra of the quasar[7] reveal narrow CaII and NaI absorption at 1371, 1417, and 1545 km s^{-1}. Radio spectra of the quasar[9] have shown narrow HI absorption at 1420 km s^{-1}. Emission studies of the HI associated with NGC 3067 reveal an extremely disturbed distribution, with a truncated disk in the western half of the galaxy, and a tail of HI extending towards and over the quasar[8].

Our continuum observations of NGC 3067 are shown in figure 2a. The radio continuum is knotty (much like the Hα emission), and the majority of the knots are resolved, with spectral indicies of -0.9$\pm$ 0.2, as expected for synchrotron radiation from the disk of the galaxy. We also find an unresolved core, which may be evidence for a compact active nucleus. Notice the radio continuum emission extending above and below the disk of the galaxy. The projected distance off the plane is 1.6 kpc, although the emission could be from the spiral arms seen in projection.

C. 2020-370

In this pair, the quasar ($z_Q = 1.05$) sits behind a linear group of galaxies, the closest of which is a barred spiral 20" to the northwest of the quasar[10] ($v_G = 8634$), one arm of which comes to within 6 kpc of the quasar. The next closest galaxy is an elliptical which sits 45" to the east of the quasar. The relative morphology of the two galaxies suggests that they are interacting gravitationally (fig. 3). Optical spectra of the quasar[10] show CaII absorption at a velocity of 8590 km s^{-1}. Radio spectra of the quasar[11] reveal narrow HI absorption at a velocity of 8611 km s^{-1}.

Our recent search for HI emission detected signal from an edge-on spiral 3' northwest of the quasar at a velocity of 8460 km s^{-1}. There is also the suggestion of extended emission in the velocity range 8580 to 8640 km s^{-1}associated with the spiral close to the quasar. Nancay

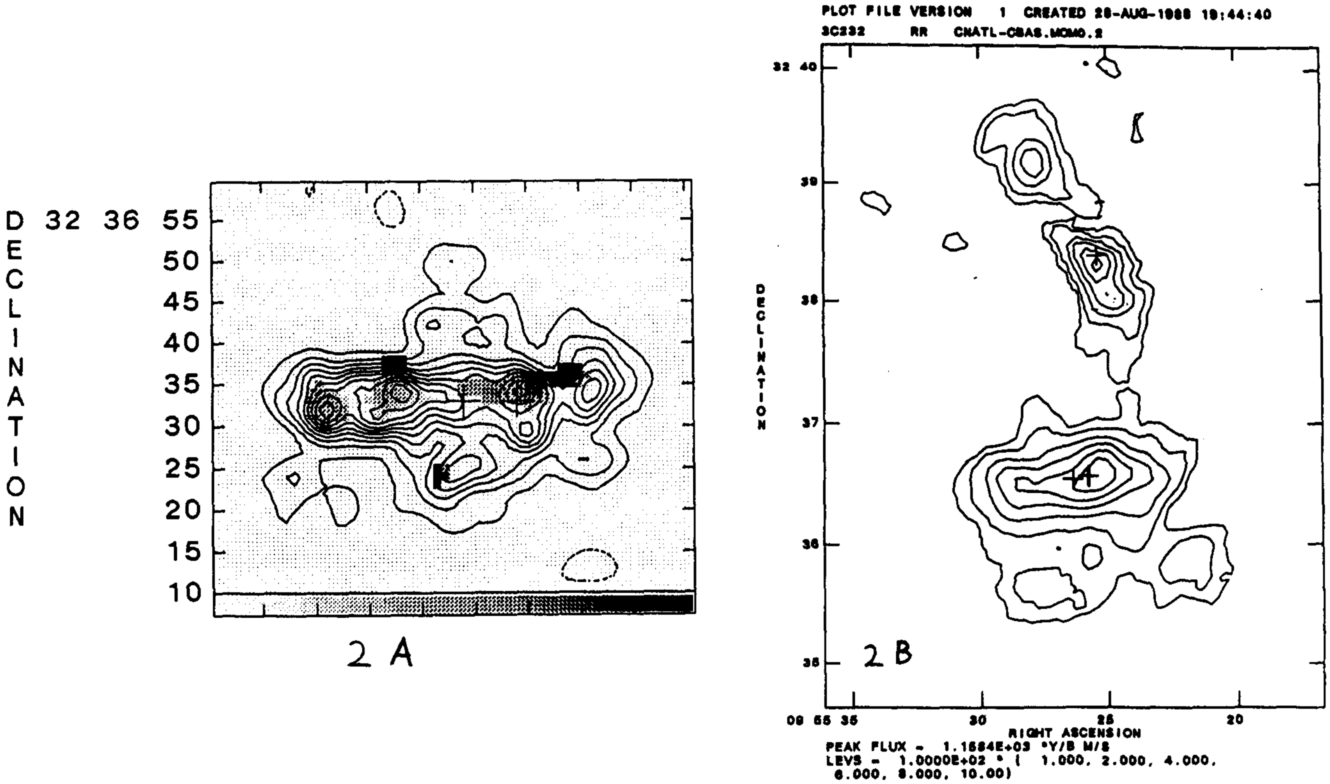
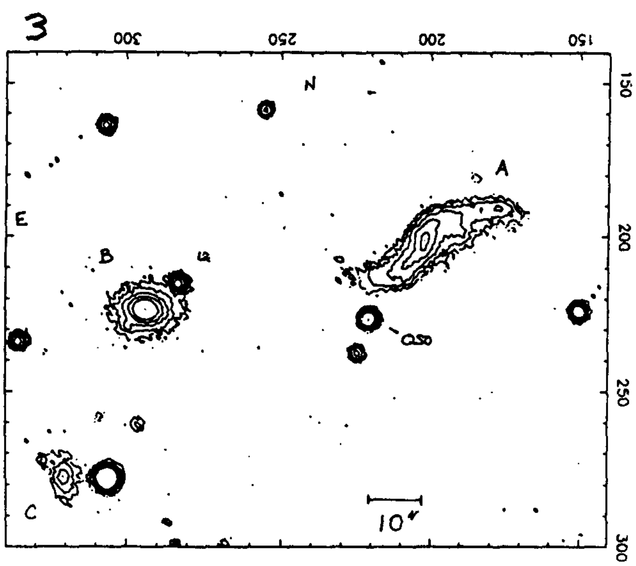
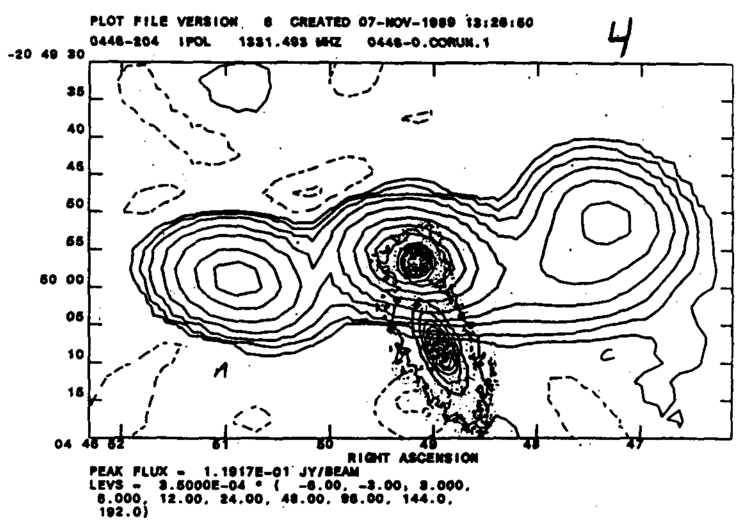


Fig. 2: A. A radio continuum image at 1450 MHz, 3" resolution of NGC 3067, with a greyscale of spectral index between 6 and 20 cm. Crosses mark the position of the optical (east) and dynamical (west) centers of the galaxy. B. HI column density. Units are 3×10^{20} cm^{-2}. The position of the quasar 3C 232 is marked by a cross to the north.

Fig. 3: A. Optical field of the quasar 2020-370.

Fig. 4: An overlay of radio continuum contours at 1330 MHz, 10" resolution, and optical contours[12] of the pair 0446-208.





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observations of this system detected an HI mass of 5.4×10^9 $M_\odot$ in this velocity range[6].

D. 0446-208

In this system, the quasar (z_Q = 1.90) sits 13" from the center of an inclined SO galaxy[12] (v_G = 20070 km s^{-1}). The galaxy is 26' from the center of the cluster A514, and the quasar lies at the edge of the optical disk of the galaxy. Optical spectra of the quasar reveal two NaI absorbing clouds at velocities of 19950 and 20040 km s^{-1}. CaII absorption is also seen, although in spectra of lower spectral resolution. From the ratio of NaI to CaII column densities, Baldwin *et al.* (1985) argue for absorption by a gas cloud in the disk of the associated galaxy.

Our radio continuum image of this source shows an extended background radio source (fig. 4). We do not detect absorption against any of the radio continuum structures at our highest spectral resolution of 5.8 km s^{-1}. We set a 3σ upper limit to the HI column densities towards the core of $2.9 \times 10^{17} \times T_s$ cm^{-2}. We detect no emission in the field to a 3σ level of 1.2 mJy/beam at a resolution 23 km s^{-1}. We set a limit of 1.1×10^9 $M_\odot$/channel for any HI within about 6' of the galaxy, in the velocity range of 19850 to 20120 km s^{-1}.

Discussion

From our limit sample, we draw the tentative conclusion that detecting absorbing gas well outside the optical disk of a galaxy signals a disturbed/interacting system which is evolving on short timescales (*i.e.* $0.1 \times H_o^{-1}$). If this conclusion holds for systems at higher redshift[14], then we have a number of interesting implications. First, it becomes uninteresting to discuss the statistics of quasar absorption lines in terms of extended halos of normal spiral galaxies. Second, the frequency of observed absorption systems requires that there be many systems still evolving on dynamical timescales down to a redshift of at least 0.5. In fact, the space density of these systems must have been about 1/10 that of field spirals. We should point out that observations of a number of higher redshift absorption line systems indicate that the galaxies associated with the absorbing clouds are not normal spiral galaxies[15]. In almost every case, the associated galaxy shows very bright [OII] emission, indicative of a starburst. Often, the [OII] emitting regions are distributed over a fairly large region (a few hundred kpc).

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